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PROPOSED PRELIMINARY CRITERIA FOR SPACE SHUTTLE ACCESS EQUIPMENT AT THE OPERATIONAL SITE



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CRITERIA FOR SPACE SHUTTLE ACCESS EQUIPMENT
AT THE OPERATIONAL SITE P. Beck, E. (NASA)
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PROPOSED
PRELIMINARY CRITERIA FOR
SPACE SHUTTLE ACCESS EQUIPMENT
AT THE OPERATIONAL SITE

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A. INTRODUCTION

The configuration of the booster and orbiter space shuttle vehicles are similar to that exhibited in high performance aircraft currently being designed for military use. However, these space vehicles will be much larger than any aircraft presently being developed. In addition, their dual operational role of space and in the atmosphere flight modes will introduce special access problems due to the variety of equipment/systems that will have to be serviced. Thus, access by personnel to the appropriate work areas requires special attention.

B. SCOPE AND BACKGROUND

This investigation was limited to accessibility to the flight hardware but did not include developing criteria for umbilical towers and swing arms. Although not covered herein, it must be understood that the flight hardware design must also permit necessary accessibility to the lowest line replaceable unit (LRU) of the components. If the latter is not a feature of the flight hardware design, the design of the ground equipment will not always be able to make up the difference to meet the goal of a two week turnaround time between missions.

This investigation was deemed necessary after a review of the maintenance/maintainability and manufacturing plans produced by the two prime Phase B space shuttle contractors, North American Rockwell and McDonnell Douglas Astronautics Company (NR and MDC).

A comparison was made between the methods of access utilized, or proposed, by the military, commercial airlines and the space shuttle Phase B contractors. Such methodology was subjected to consideration for space shuttle use and similarity to current space shuttle access concepts. The Phase B contractor concepts were in turn examined for degree of use of the state-of-the-art and progressive extension of new cost-effective ideas.

This comparison disclosed a need for better definition of the criteria/requirements for space shuttle access equipment. Detailed requirements (specifications) cannot be provided at this time due to lack of definition of the eventual general arrangements of the vehicles. Preliminary criteria is, however, needed prior to initiation of the detail design (Phase C/D effort) of ground hardware for the operational site. Proposed criteria to meet this need is presented herein.

C. ASSUMPTIONS

The following assumptions were used in the investigation and for development of criteria:

1. Level I Program Requirements, dated February 12, 1971
2. Approximately five orbiters and four boosters must be accommodated (being serviced or protected from the elements) at one time at the operational site.
3. Flight vehicle configurations as of May 1971
4. At least part of the final assembly will be performed at the operational site
5. Part, or all, of the flight testing and refurbishment will be performed at the operational site
6. Flexibility in use and interchangeability of access equipment for various functions are cost-effective criteria
7. Vehicles will be erected vertically on a launcher in a high bay (Apollo method) or mated in the horizontal attitude and towed to the pad for erection to the launch (vertical) attitude
8. Cargo handling and the presence of passengers is limited to the orbiter. All the other functions apply to both type vehicles.

D. DISCUSSION

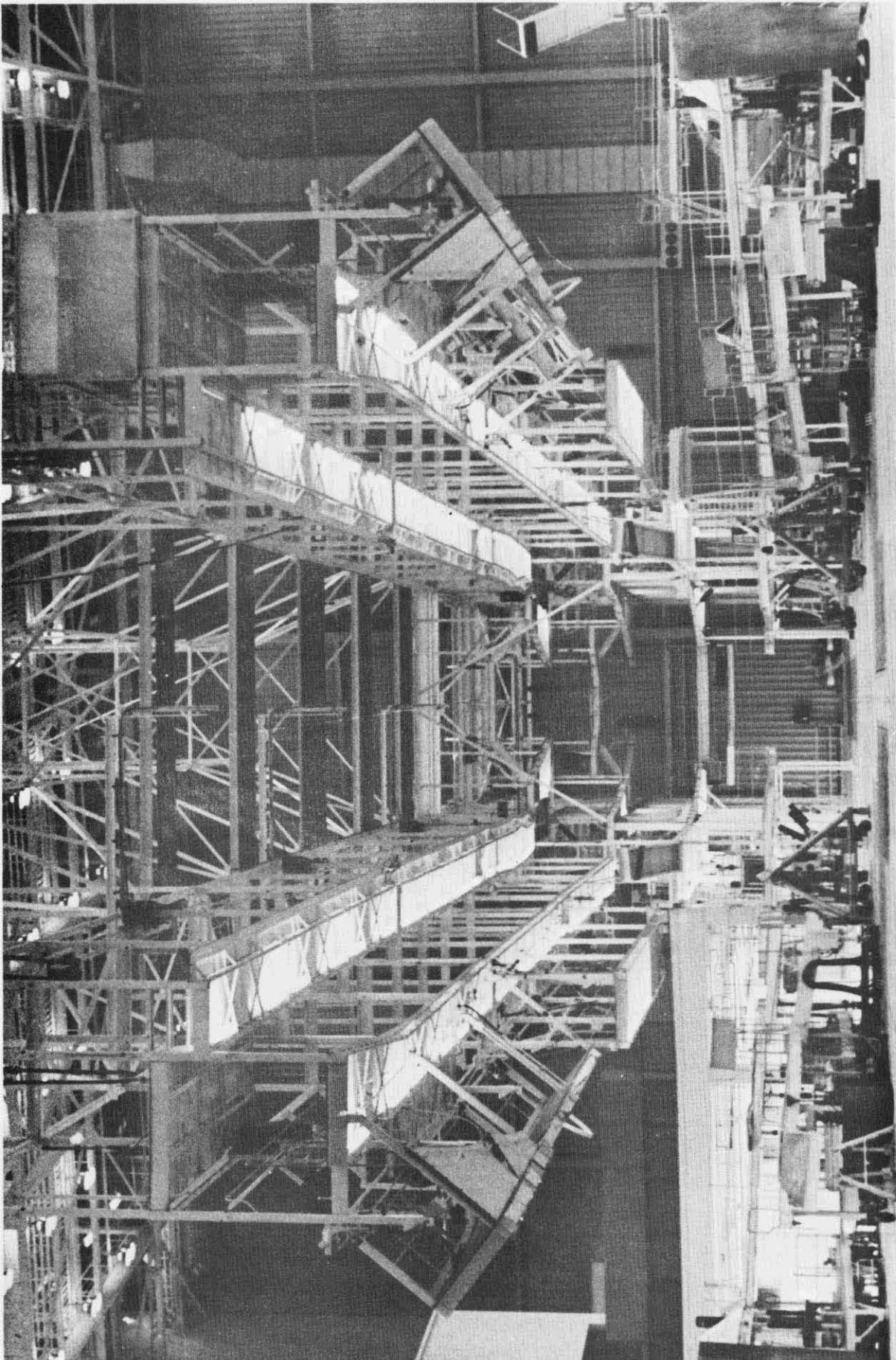
1. Airline Maintenance

Maintenance areas for the Boeing 747 show a profusion of access equipment, Figures 1 through 5. The aircraft is carefully placed inside the access equipment structures, Figure 2. The engine nacelles fit into slots of this structure. Then, platforms behind the nacelles are rotated from the vertical to the horizontal position (Figure 3) to provide access to all parts of each engine. The size of the engines requires that the access equipment feature more than one working level to allow mechanics to reach all the areas that will undergo inspection and repair.

The entire structure of the aircraft has to be routinely inspected from the outside to detect any evidence of structural or corrosion problems. That is the reason why the platforms are placed above and along side the aircraft (Figure 2).

Access to the vertical stabilizer requires tall access stands that are mounted on rails that run transverse to the fuselage of the aircraft (Figure 4). This permits placement on each side of the aircraft after entry into the maintenance bay (Figure 2).

Routine maintenance of the landing gear and associated doors requires placement of the aircraft on jacks high enough to have full extension of the oleo struts which



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Figure 1.

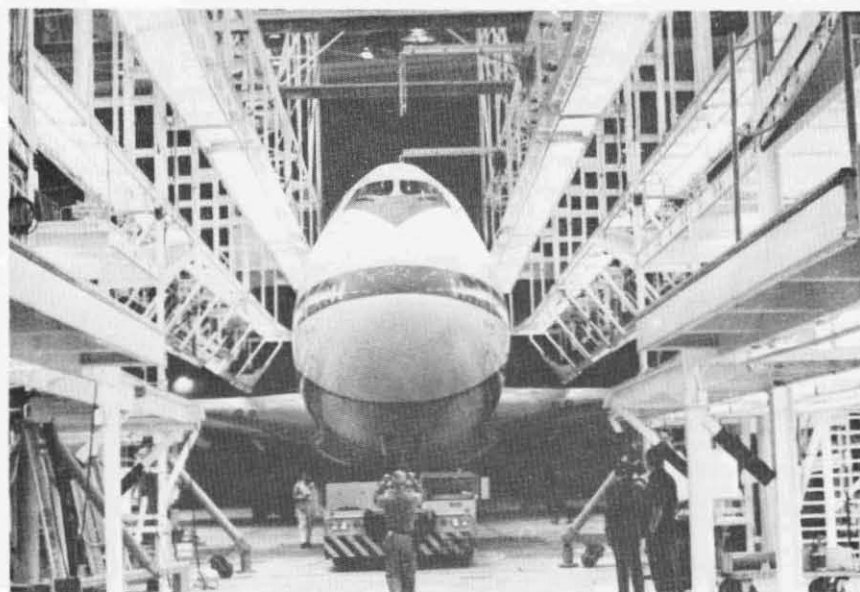
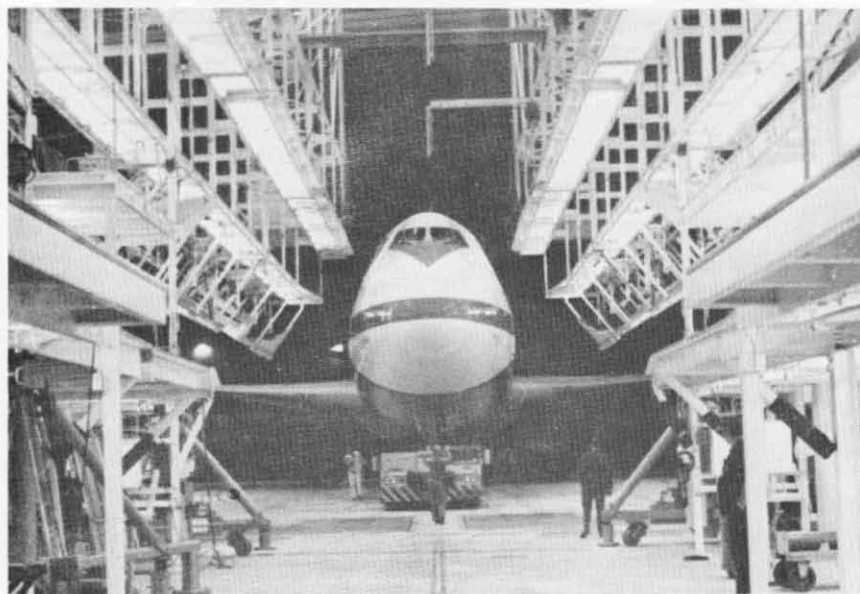
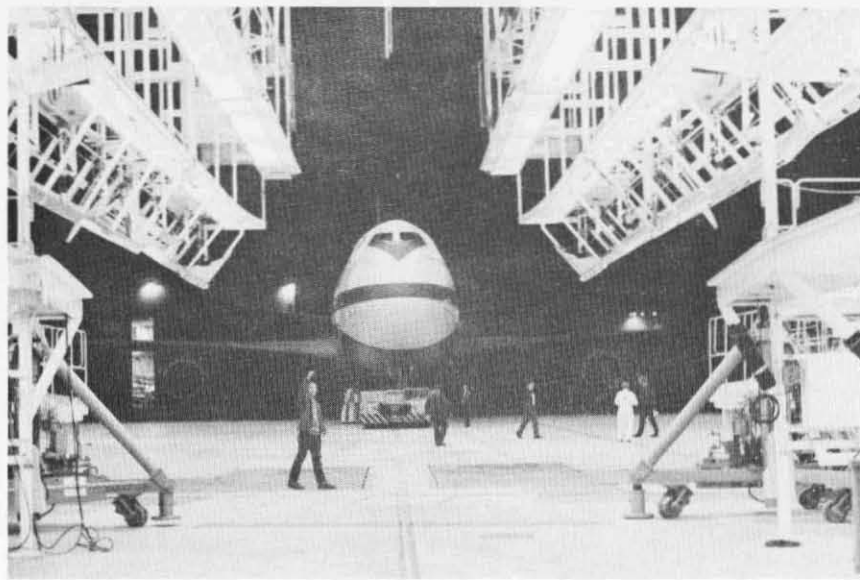
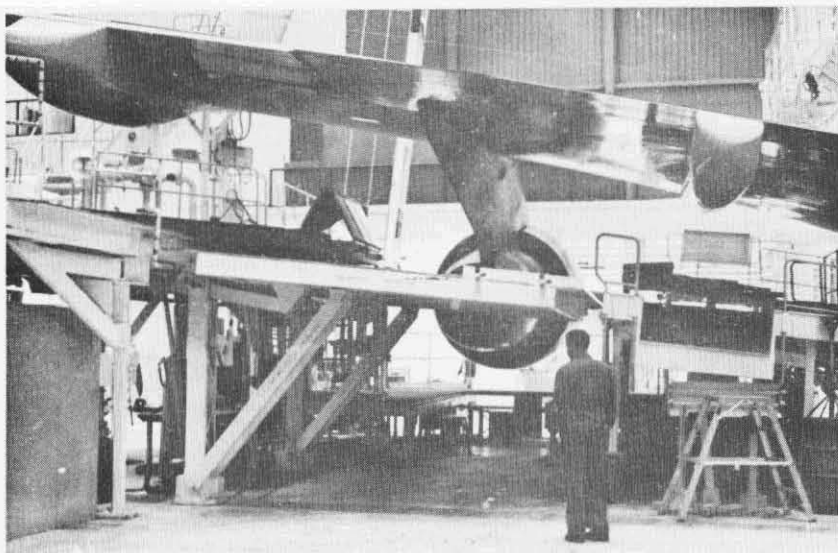
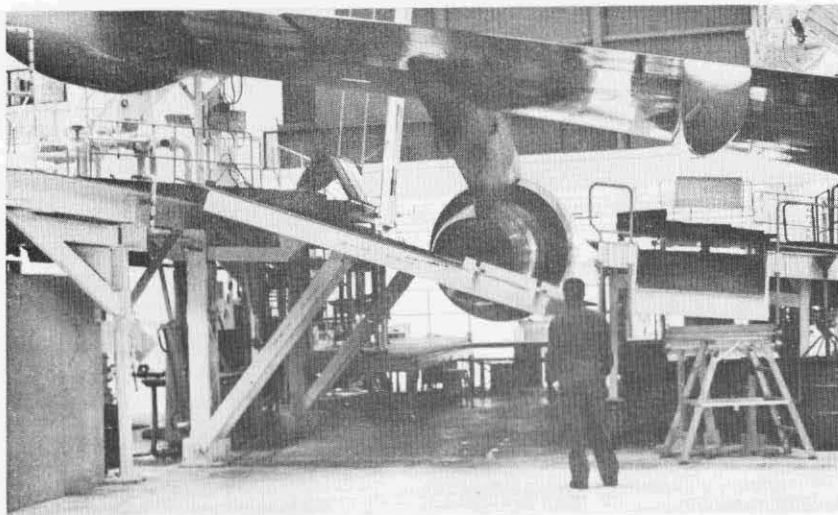
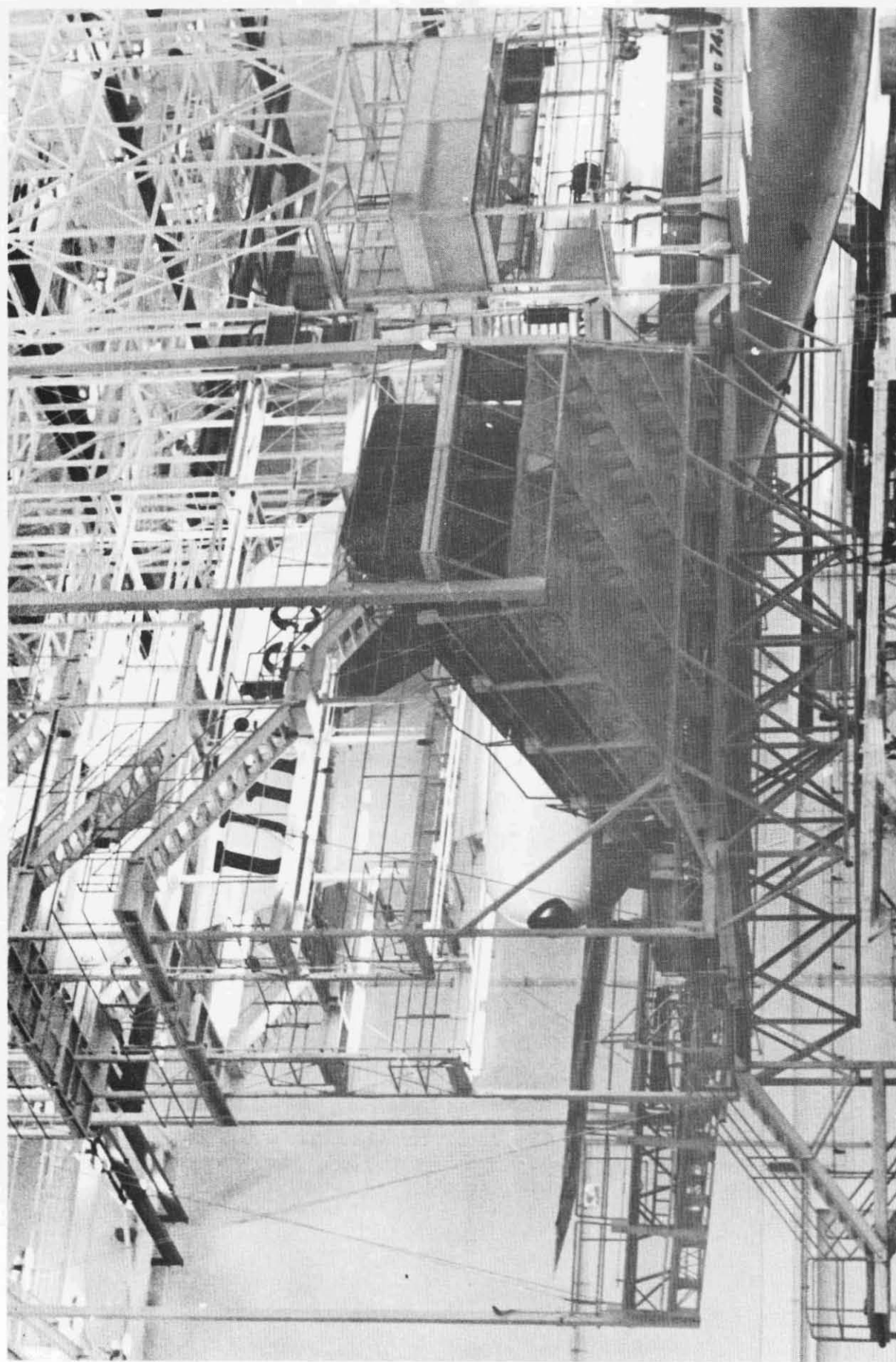


Figure 2.



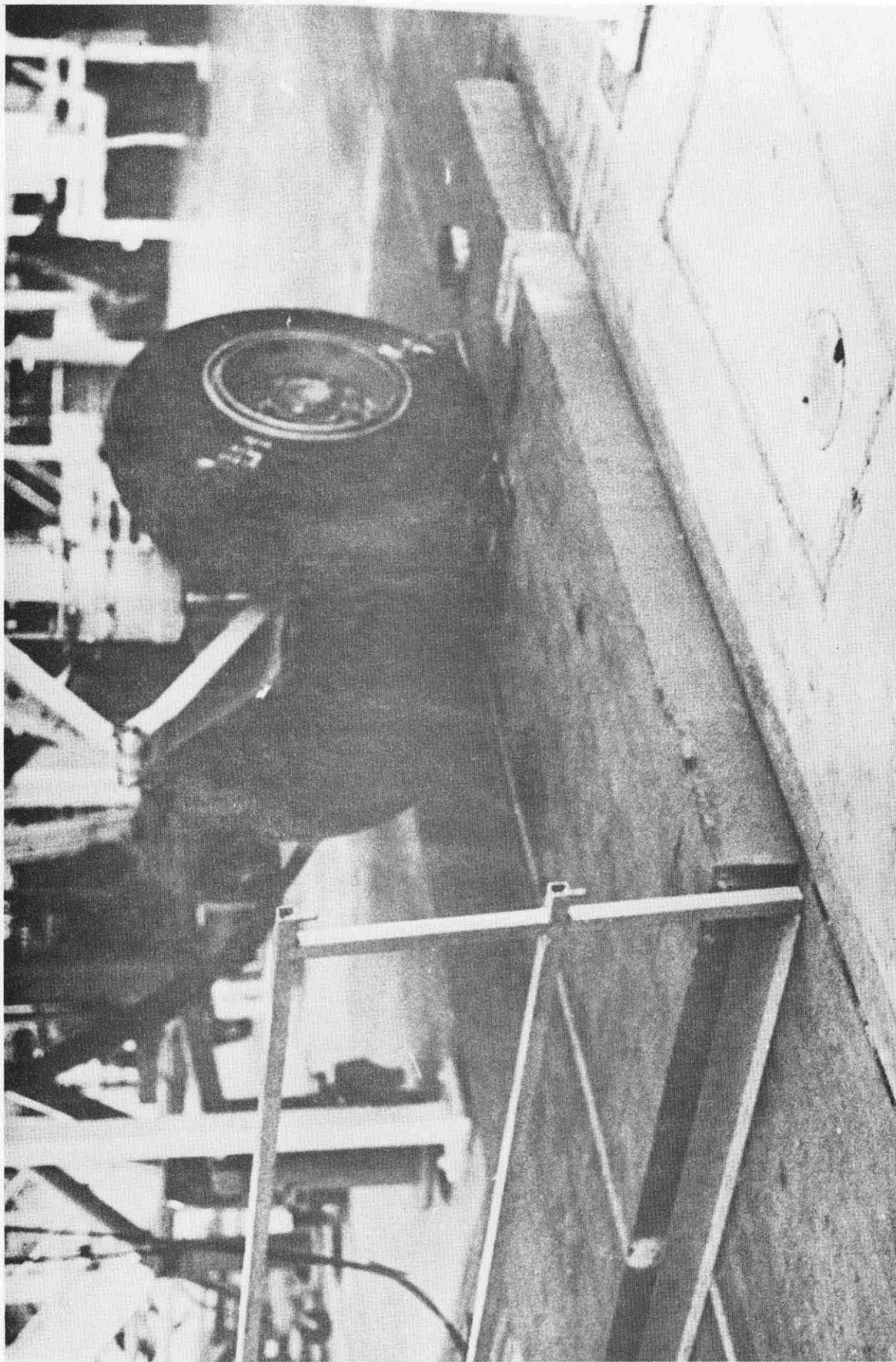
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Figure 3.



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Figure 4.



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Figure 5.

then allows gear retraction. In the case shown in Figure 5, this is accomplished by elevators under each of the three landing mounts that raise the aircraft about 9 inches. Jacks are then placed under the aircraft after which the elevators are lowered approximately 8 feet leaving the landing gear suspended in the air. At this point the landing gear maintenance effort can begin.

There is variance in the maintenance bay layouts between airlines and locales but they all follow the basic concepts shown in Figures 1 through 5. This basic concept is to permit access to all parts of the vehicle at one time, especially in the areas where there are hydraulic cylinders, actuators, gear drives, and/or electronic equipment.

The advantages of this concept are that it:

- a. Permits simultaneous access to all parts of the vehicle at the same time.
- b. Features dedicated equipment that is put in the same place each time for the maintenance crew thereby reducing errors and hangar crashes (collision in the hangar between aircraft or aircraft with the GSE).

The disadvantages are that:

- a. Hangar space is dedicated to a single operation in a single area thereby eliminating any subsequent choice in area or access equipment utilization.
- b. The access equipment would have to undergo extensive modification to accommodate any other shape (or size) vehicle general arrangement.

2. Military Aircraft Maintenance

Even when using the same type of aircraft or engines (as the commercial airlines), military maintenance concepts differ significantly from the airline approach. The access requirements are identical but the situations and frequency of service varies a great deal and this impacts the access equipment requirements. The major differences for the military are:

- a. Shorter engine life due to prolonged operations at higher power settings (higher temperature accelerates turbine and burner wear).
- b. Need for mobility to shift the maintenance activities from one locale to another due to a change in military mission requirements.
- c. Prolonged operations from advanced bases which are not as well equipped as major airline or military terminals.

These differences result in an emphasis on mobile access equipment rather than fixed installations as shown in Figures 1 through 5. This in turn has a significant

impact on the maintenance facility layout. Emphasis is placed on making maximum use of the area whether it be a permanent (land based) hangar or the hangar deck of an aircraft carrier. The flight vehicles are stacked to make the best use of space rather than being lined up side by side. This layout insures that there is adequate space to move handling, access, and servicing equipment between the vehicles. The arrangement also insures a clear path for a tug with low bar and adapters to get to the nose wheel to move the vehicles. Such a layout requires larger door openings so the vehicles can be moved in or out of the area with minimal or no turning. This is important because turning:

- a. Increases the chances for a "hangar crash"
- b. Larger vehicles require larger turning radii (especially at the wing tips)
- c. Increases the loads on the landing gear

Land based hangars for larger military aircraft often feature cutouts above the doors and/or "dog houses" that cover an opening in the doors to accommodate those having higher vertical stabilizers. Such arrangements present servicing problems but are not insurmountable. Naval aircraft feature folding wings and (sometimes) folding tails, to permit dense stacking on the hangar deck for storage purposes.

Almost all such access equipment therefore features wheels or skids and modular construction to permit easy disassembly and transporting to other areas. Jacking the aircraft to service the landing gear is a standard procedure versus use of elevators as shown in Figure 5. This increases overhead clearance requirements to accommodate the empennage.

The advantages of this concept are that it:

- a. Allows interchangeability in use of equipment for more than one purpose in more than one location.
- b. Simplifies remote base support and unscheduled maintenance requirements (less special gear).

The disadvantages are that:

- a. Personnel have to relocate all the access equipment before starting work on a vehicle.
- b. Equipment movements increase the chances of a "hangar crash."

3. Space Shuttle Maintenance

As stated in Section A of this report, the space shuttle will not be uniquely similar to the commercial airline or military with regards to maintenance. The only points of close similarity are:

- a. Access will be needed to every area of the two vehicles
- b. Servicing the airbreather turbine engines
- c. Handling and access with the vehicles in the horizontal attitude
- d. Servicing the aerodynamic control system

E. CRITERIA PARAMETERS AND RATIONALE

1. General

Access equipment will be required to permit personnel to inspect and service all exposed or exposable structure within and outside the boosters and orbiters. Access is also needed to reach each replaceable, LRU, component with the vehicles in the horizontal attitude.

The basic access requirements stated above also apply to final assembly, cyclic maintenance, and refurbishment activities. These activities are very similar in nature except that final assembly and refurbishment results in the exposure of more equipment and parts than experienced in cyclic maintenance. Regardless of the degree of exposure or depth of the assembly/repair activities the general criteria for access remains the same; only the dimensions change. Special equipment at the operational site for each of the activities listed above would result in a high degree of cost redundancy and a lack of operational flexibility. Except for a minimal number of special cases, the access equipment should be interchangeable between site activities.

In the interest of servicing two different flight vehicles in the same facility and the need to limit facility size, it appears that the dedicated fixed installations covered in Part I of Section D, would not be the most cost effective approach to the problem. Shape of the vehicles will probably be similar to military aircraft (1970 era) utilizing a capital T, cross +, or most likely a delta planform. Parking in a minimum space to reduce the floor space requirements would be difficult due to the space required for any fixed installation access equipment or to reposition the hardware. Providing for one set of equipment to handle a vehicle on each of its' two sides is possible. This, however, appears to complicate the design since the equipment would have to be capable of movement along all three axes.

Installation and servicing of rocket engine clusters, such as will be used on the booster, can best be accomplished with the vehicle in the vertical (launch) attitude. This arises from Saturn IB and V experience, proven designs to optimize the structural weight of the associated hardware (stiffeners to properly align the engines), access to all the engines in the cluster, and allowing a single location for the low point fuel line drains (affects interchangeability). However, at present, it appears that it will be necessary to provide access for maintenance in both the horizontal and vertical attitudes.

Table 1 shows that a significant number of the access requirements for a particular function applies to more than one locale at the operational site. This points

Table 1. Functions vs Location for Ground Operations That Require Access Equipment

FUNCTION LOCATION	Post Landing Activities					Maintenance		Checkout		Mating Vehicles		Cargo Activities				Launch Activities		
	Crew and Passenger Egress	Cargo Service	Remove Equipment	Safing/Purge	Inspection	Unscheduled and Instal Changes	Schedule	Preflight Operations	Final Preparations	Vertical Rollout	Horizontal Rollout	Instal	Checkout	Remove	Service	On Pad Servicing	Crew and Passenger Ingress/Egress	Countdown
RUNWAY	E																	
SAFING AND DESERVICING AREA		XX	X	X	X				X (Note 2)					XX	XX			
OPERATIONS AND MAINTENANCE (O&M) FACILITY						XX	X	X	XX			XX	XX	XX	XX			
FINAL ASSEMBLY (OR REFURBISHMENT) FACILITY (Note 1)						XX		XX	XX (Note 2)									
VEHICLE INTEGRATION AREA (Note 1)							XX	X	XX	X	X	XX	XX		XX			
LAUNCH PAD						XX			XX			XX	XX	XX	XX	X	XE	X

Note 1: This will probably be a part of the O&M facility.
Note 2: For horizontal take-off flight operations only.

Legend: X Predicted normal activity
XX Alternate Procedure (May be done in whole or in part at other locale)
E Emergency capability requirement

out a need for interchangeability of access equipment. It is apparent that a particular piece of access equipment should not be limited to use in one locale or for only one purpose. There is no apparent need to relax such a requirement except for the final assembly function, as noted in the next paragraph.

Access equipment required for final assembly will differ from that for launch operations. Personnel have to work in areas prior to the permanent structural assembly of the elements that are no longer accessible after completion of that activity. Since such equipment will be ideal to support the subsequent refurbishment activities it will remain in service as long as the operational equipment. It follows that since all these functions (final assembly to end of program) are proposed to take place at the operational site the final assembly access equipment should be useable, if needed, in the maintenance areas. Operational equipment would not always be useable in the final assembly or refurbishment activities due to the different access requirements. Such difference being normal maintenance of parts replacement and limited modifications versus assembly or disassembly of systems or major structural elements.

2. External Access (Horizontal Attitude)

This access requirement only differs from contemporary military and airline needs with regard to size. Whatever the activity, access to every inch of the exterior of each vehicle is necessary. This suggests the use of modular access equipment that can be expanded like a building block structure. Sizing and flexibility of the modular construction needs to accommodate reaching the following areas (see Table 2):

- a. Underside of fuselage and thermal protection system which can be as much as 10 to 16 feet above the ground.
- b. Sides of the fuselage which can have heights as much as 60 feet.
- c. Top of the fuselage by bridging across to the other side, somewhat similar to that used on the Boeing 747, Figure 6.
- d. Top of the vertical stabilizer and rudder(s), Figure 4, which can exceed 102 feet.
- e. The canards that can be as much as 40 feet above the deck.
- f. Aerodynamic control surfaces and skin of the wings (Figure 7).
- g. Cargo bay of the orbiter (from the top side).
- h. Avionics compartment (probably in the nose of the vehicles).
- i. Crew compartments.

Table 2. Representative Horizontal Attitude Dimensions for External Access (FEET)

<div> <div>DIMENSION (FEET)</div> <div>VEHICLE</div> </div>	FROM THE GROUND*										Wing Span	Length	Canard Span
	Underside at	(1) Nose Wheel	(2) Main Gear	Top of Air-breather Engines	Top of Upper Rocket Engines	Top of Wing	Top of Stabilizer	Cockpit Access	Top of Canard	Top of Fuselage			
NR/GD Booster		12	13	14	56	23	102	33	37	47-56	143.5	323	67
MDC Booster		4.8	3.2	11	46	55	72.5	32	11	49	166	270.5	72
MDC Orbiter		10.5	10.5	11	44	21	73	37	N/A	41	107.5	174.7	N/A
NR Orbiter		6.7	13	36	35	22	60.8	29	N/A	30-38	107	206.2	N/A

*Placing vehicles on jacks to service the landing gear will increase dimensions four (4) to eight (8) feet.

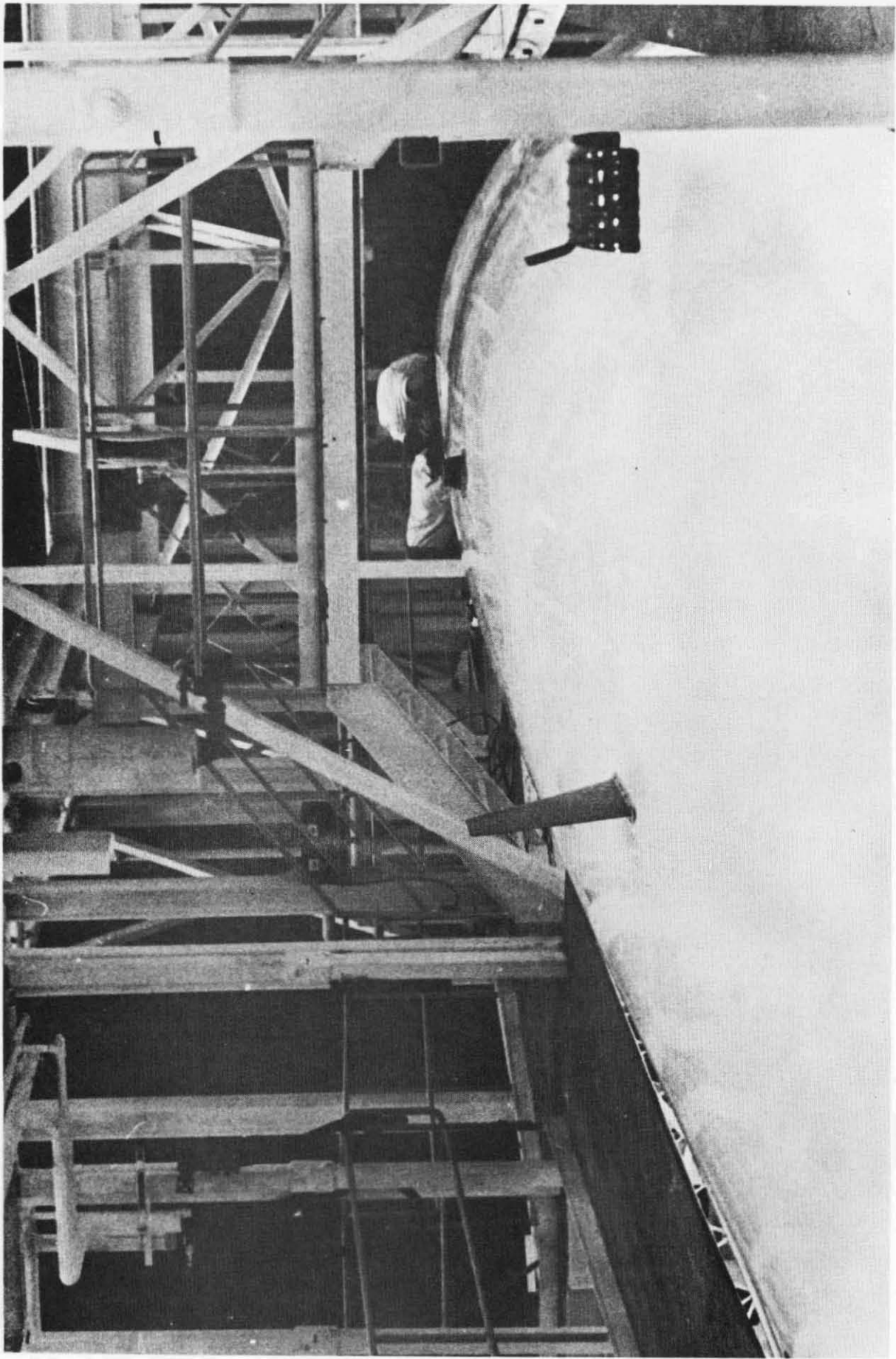


Figure 6.

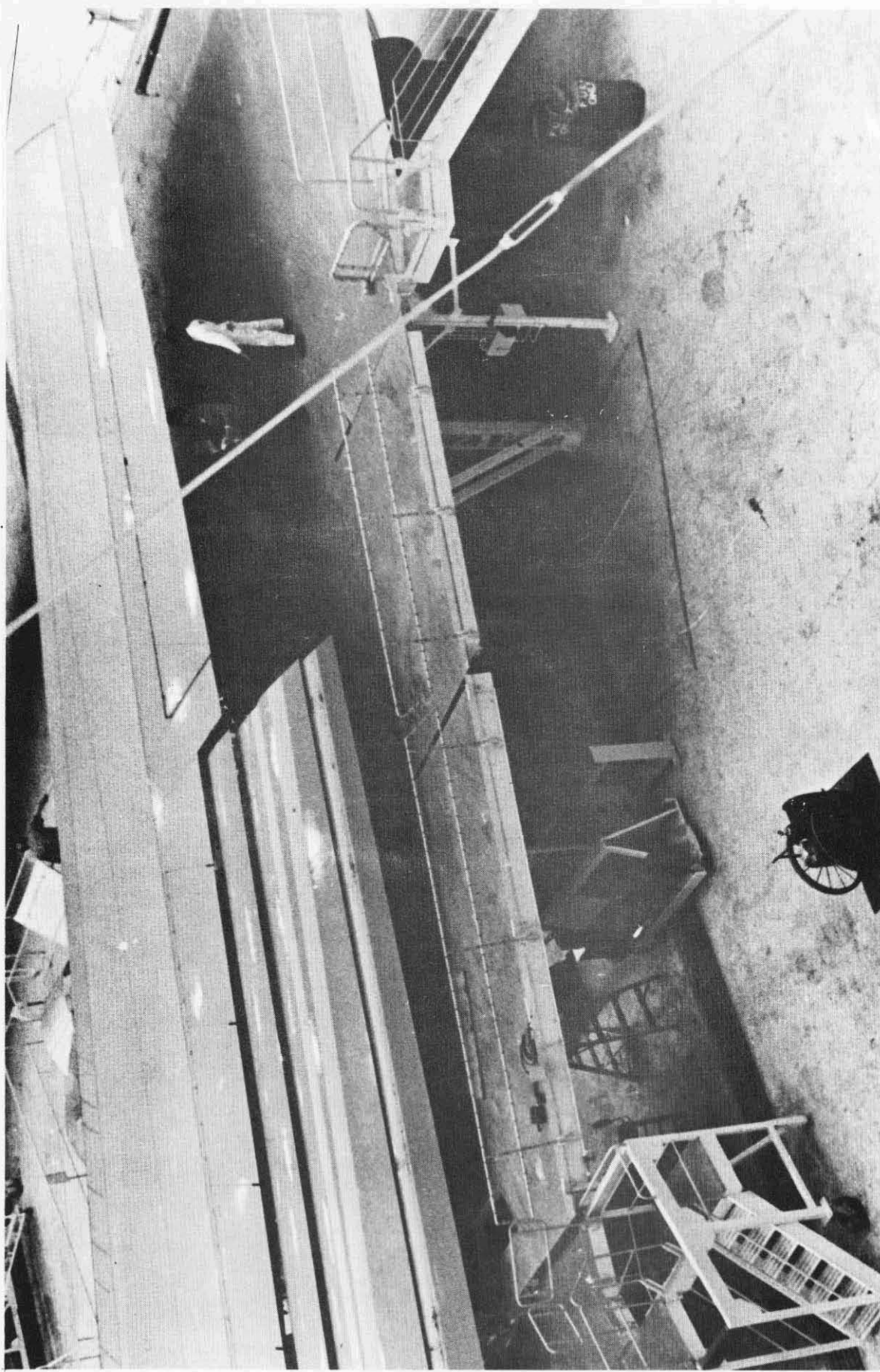


Figure 7.

j. Airbreather engines which may be under the wings, on top of the fuselage, or in the canards.

k. Rocket engines in the tail.

Both the size of the access equipment and the weight of some of the items that may require placement or replacement dictate a need for mechanical lifts. Provisions should be made for installation of hand operated winches. A small freight elevator in the larger stands is also needed. Such equipment will reduce the mobile crane requirements at areas the bridge cranes cannot reach and should prove to be less expensive.

Particular attention is required to provide adequate access to the airbreather engines. Such engines are presently designed to be inspected and serviced principally from the side. If the engines are hung under the wing, as presently shown for the NR/GD orbiter, present day practices and access equipment will be adequate both for service and engine change. Upper fuselage locations like the NR orbiter, will require more consideration due to their positions over the fuselage.

It is to be noted that one current booster design features five airbreather engines, laying side by side, in a canard structure with very little space between them. Such a design will make it extremely difficult to obtain access to each engine, to perform borescope inspections, component replacements, trimming the engines (with respect to each other), and checking out the fuel control and assemblies components. All the above activities are necessary proven routines, Appendix A, that will require access for the "care and feeding" of airbreather turbine engines.

In addition, designers must remember that the final trimming and fuel control adjustments can only be made with the airbreather engines running. Fortunately these latter two adjustments are not required before each flight. They result from an engine change and/or change out of the fuel control systems. Such changes are made on a relatively minimal basis but it does create a requirement for access equipment.

Servicing the airbreather jet engines, landing gear, a majority of the avionics "black boxes" (most of which will be located in the area of the cockpit), and visual inspection of the exterior structure can be best accomplished with the vehicles in the horizontal attitude. Completely mobile access equipment can be utilized.

Rocket engine maintenance in this attitude would be limited but the stacked arrangement will require cantelevered bridges off the basic access stands to get between the engines.

Horizontal mating of the booster and orbiter (if used) will require access to the top of the fuselage of the booster. Access equipment cannot interfere with the positioning of the orbiter.

It will be necessary to provide a rocket engine change-out capability during maintenance regardless of the attitude (vertical or horizontal) of the vehicles. A current objective in the space shuttle of minimizing the time on the launch pad appears to preclude any need to change rocket engines on the pad. This will be particularly true if there is only one launch pad (due to budgetary constraints).

The flight vehicles will be landing at one or more of the available suitable runways. The booster will probably return to the launch site but the orbiter can easily return to another site within the continental United States. In the event of a landing elsewhere than the operational site it will be necessary to service the vehicle(s) in the horizontal attitude for a ferry trip back to the home base. Since a versatility is desired to select from a number of possible landing sites, the access equipment for this purpose must be transportable by air. There will be a need to support:

- a. Crew and passenger ingress/egress
- b. Purge, hydrogen venting and/or environmental air connector(s) hookup
- c. Access to the thermal protection system
- d. Possible installation of a tail cone over the rocket engines bells
- e. Scheduled/unscheduled maintenance of the airbreather engines
- f. Fueling with JP type fuel
- g. Ground power service hookup/detach
- h. Engine(s) start

Landings (and take-off) away from the operational site is a firm operational requirement. Therefore, access equipment to support such activities should be made a part of the operational sites' inventory. It is not considered cost effective to provide even a minimal amount of equipment for all the possible landing sites. Fully mobile, air transportable access equipment could readily support any locale where the orbiter can achieve a safe landing.

3. External Access (Vertical Attitude)

- a. Vertical stacking in a high bay on a mobile launcher

Two separate access problems will exist if the vehicles are erected on a launcher inside a facility (Apollo concept). In this case access will be needed within the facility to:

- (1) Reach the mating pads to unite the vehicles.
- (2) Allow full access to all compartments such as cargo bay, cockpit, avionics area, etc.
- (3) Accommodate rocket engine changeout. (Will not need to change out the airbreather engines since all checkout would be completed prior to stacking.)

b. Reach and service umbilicals

Such requirements can be satisfied in part, by use of the mobile launcher and swing arms as an access platform. Any additional access needs will have to be satisfied by the design of the ground support access equipment.

c. On the launch pad

Regardless of the stacking procedure to be used, access to the vehicles on the launch pad is a firm requirement to get to:

- (1) Crew and passenger compartments
- (2) Rocket engines
- (3) Cargo in the orbiter
- (4) TPS and landing gear (only for unscheduled maintenance)
- (5) Umbilical(s) connection point(s)

F. GENERAL CRITERIA

1. General

Access equipment to support ground activities at the operational site is needed for personnel entry (and egress) to the two types of flight vehicles, boosters and orbiters, during:

- a. Final assembly and refurbishment
- b. Post landing activities
- c. Unscheduled maintenance
- d. Scheduled maintenance and checkout of readiness for launch
- e. Launch preparations up to ignition and/or lift-off

The functions b through e above will normally take place in the areas shown in Table 1. Final assembly and refurbishment will take place within or adjacent to one of the facilities shown in Table 1.

Basic design concepts shall be to avoid fixed installations (permanently attached to a building) and provide for interchange ability between work areas and the various functions. Exceptions to these concepts will be allowed for final assembly and refurbishment. Such equipment should be useable for other operations but the operational equipment will not always be suitable for manufacturing or major rework purposes.

Access equipment shall be designed to permit use of a modular building block concept that will provide units that can be added together to accommodate the various dimensions of the flight hardware, Table 2.

Provisions shall be made for the attachment of winches to the access equipment to handle equipment which weighs more than 30 pounds. Small freight elevators should be provided where the vertical height to be achieved is greater than 20 feet.

Equipment to be used at the alternate sites shall be air transportable using existing transport aircraft. Such equipment shall also be capable of being integrated into the operational site access hardware.

The design of the operational site access equipment shall not be compromised to meet manufacturing or refurbishment needs.

The use of bridge or mobile cranes for access shall be minimized.

The useful life of the access equipment supporting final assembly and flight testing shall be 15 years. The life of the operational hardware will be 10 years.

Emergency egress utilizing ground access equipment, in whole or in part, is required to permit the crews (and passengers) to:

- a. Abandon the vehicles after a landing whenever an emergency condition exists.
- b. Escape to a safe place when the vehicles are on the launch pad and an emergency condition exists.

Time lines for emergency egress shall be equal to or less than those used for on pad emergency egress from the Apollo spacecraft at Launch Complex 39. Two modes of operation must be considered for emergency egress from the launch pad. These are:

- a. Flight crews only, numbering up to six people.
- b. Flight crews and passengers only numbering up to 18 people.

2. Vehicles in Horizontal Attitude

Access equipment is required to support inspection and repair (when required) activities at any point on the external surface of the vehicles.

Landing gear access for checkout and adjustment is also required. Landing gear maintenance requires placing the vehicle on jacks. Access equipment design shall accommodate jacking which will involve raising the vehicle(s) somewhere between three and eight feet above the normal static position.

Access is needed to all parts of the moveable aerodynamic control surfaces similar to that shown in Figure 7.

Access to the hatches, openings, etc., shall be provided to permit reaching internal areas of the vehicles to service flight hardware down to the LRU's and also certain structures.

The airbreather and rocket engines will require inspection after each operation along with component or engine replacements. Personnel access to all exposed engine areas (top, sides, and bottom) is necessary. Such access equipment shall also permit entry into areas between the engines or between the engines and structures where adequate clearance exists.

If vehicle mating is to take place with the vehicles in the horizontal attitude access equipment is needed to allow personnel to achieve the hookup without interfering with the necessary placement of the orbiter.

3. Vehicles in the Vertical Attitude

a. In the Vehicle Integration Area

After placement of the booster on the launcher, personnel require access to the holddown mechanisms. Mating with the orbiter requires access to the attach points without interfering with the placement of the orbiter.

Access is required to umbilical points, all hatches, and inspection/service parts and the rocket engines to complete preparatory work. No requirement exists for access to the airbreather engines from this point on in the ground activities. Rocket engine replacement capability is a requirement and suitable access equipment is required.

b. On the Launch Pad

Access is needed to the umbilicals, cockpits, passenger compartment, and the cargo.

Access to other hatches, inspection parts, engines, etc., would be only for unscheduled maintenance rather than a regular operation. Temporary type access equipment should be available to meet these unexpected conditions.

APPENDIX A

JET ENGINE SUPPORT REQUIREMENTS

A. Case 1 - Engines Permanently Mounted in the Booster

1. Equipment and Facilities

Base Support:

- a. Engine assembly and maintenance shop
- b. Engine storage and receiving building
- c. Handling equipment including:
 - (1) Hoists
 - (2) Mobile buildup stands for parts and complete engine
 - (3) Access platforms
- d. Special and standard tools
- e. Tugs
- f. Engine test cell
- g. Aircraft runup area (desafing facility area near the runway should be adequate for this purpose)
- h. Mobile engine lifts (this equipment is used during removal and installation of engines from the vehicle)
- i. JP fuel supply and transfer system (can use trucks)
- j. Deservicer (to off-load fuel)

2. Operations

- a. Engines are received in pressurized containers and require buildup (assembly) and checkout prior to being used during flight.
- b. Buildup requires 500-manhours for the J57 engine and 600-manhours for the TF engine. The TF engine is approximately one half the size of the engine used

on the C5A. The C5A engine requires approximately 1000-manhours. The most efficient size work crew is four or five experienced mechanics.

c. After buildup, the engine is delivered to the test cell for runup. Runup requires approximately 4 hours provided only one type of engine is being tested and that the supporting fittings do not have to be repositioned. Repositioning usually requires an additional 4 hours.

d. Engines are stored in pressurized containers on an as needed basis. Maximum storage life is 90-days as a result of environmental limitations.

e. After engine installation into the vehicle (2 hours), a runup is required to "trim" the engine (adjust fuel control and linkage) and check out all systems. The runup requires 4 to 6 hours.

f. If an engine change is required downrange, the following equipment should be shipped.

- (1) Engine in a sealed pressurized shipping container
- (2) Mobile engine lift and special tools
- (3) Hoist and access platform
- (4) Buildup stand
- (5) Portable shelter

g. Engine removal and installation procedure is as follows:

- (1) Remove damaged engine from vehicle using lift
- (2) Place damaged engine on buildup stand
- (3) Place new engine on lift
- (4) Install new engine into vehicle
- (5) Store damaged engine into container

3. Normal Downrange Support

- a. Fuel storage area
- b. Fuel pit or trucks (this includes pumps and filter)
- c. Fuel checkout equipment
- d. Engine tools and equipment
- e. Access platforms
- f. Runup area
- g. Fuel deservice are (JP type)

B. Case II - Engines Installed on Booster at Downrange Site on Repetitive Basis

1. Base support requirements are the same as Case I (paragraph A).

2. Downrange support requirements includes those in Case I (paragraph A) in addition to:

- a. Lifts (two or three) for engine installation**
- b. Shelters (two or three) for engine installation**
- c. Engine storage and receiving building**